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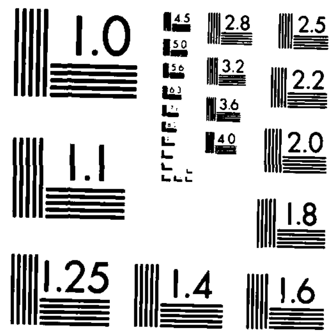

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ELEMENTS OF A BMD C^3

V&H PROGRAM

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The purpose of this report is to organize and discuss the many issues which must be addressed in formulating a V & H program for a BMD C^3 System. This effort is intended as an aid for the SENTRY Program Office (1) to keep the C^3 V & H efforts [illegible] on the major issues and (2) to indicate how C^3 design issues and programmatic issues can affect the C^3 V & H efforts, and vice versa.

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1.0 INTRODUCTION

BMD Command, Control and Communications (C^3) provides the mechanism through which BMD is monitored and/or commanded through a hierarchy of readiness levels to engage and destroy incoming reentry vehicles. In performing engagement (as opposed to peacetime) functions, BMD C^3 must operate in an extremely severe nuclear environment and must interface with other local and national C^3 systems. Local systems could include MINUTEMAN, MX, and their associated control facilities. National C^3 interfaces include the BMD Command Authority via the World Wide Military Command and Control System (WWMCCS) networks. In order for BMD to be effective, it is imperative that C^3 functions associated with these interfaces, as well as with intra-subsystem data transfer, be hardened in consonance with validated mission requirements.

1.1 PURPOSE

The purpose of this report is to organize and briefly discuss the myriad of C^3 V&H issues in order to highlight the key decisions which will need to be made on C^3. This document is intended as an aid for the SENTRY Program Office to:

- Keep the C^3 V&H efforts focused on the major issues
- Indicate how C^3 design issues and programmatic issues can affect the C^3 V&H efforts, and vice versa.

The relationship of the C^3 V&H efforts to the C^3 program as a whole will also provide a useful input to the development of the C^3 Subsystem Master Plan (to be developed by Teledyne Brown Engineering).

1.2 OBJECTIVES

There are a multitude of issues associated with a C^3 V&H program, including nuclear environments (radiation, blast, shock, etc.), environment

effects (circuit upset, signal attenuation, component failure, etc.), hardening options (hardened components, shielding, etc.), other survivability options (circumvention, link and node redundancy, etc.), design constraints (technology limits, use of GFE, etc.), and many others.

To help organize this complicated set of issues, some key questions need to be asked:

- What are the key V&H issues that could drive the C^3 design in one direction or another?
- What are the limits to what can be done with respect to resolving V&H issues?
- How can resolution of V&H issues affect programmatic decisions, and vice versa?
- What issues require immediate attention?

The answers to these questions will provide general guidance on the organization and administration of a C^3 V&H program, and will establish some priorities on the V&H issues.

This report deals primarily with top-level V&H issues, and these are not necessarily the issues of concern to people involved with the "nuts and bolts" of a V&H program. To illustrate the distinction, an example of a top-level V&H issue is whether or not buried fiber optics can be a surviving, enduring link in the C^3 network. The "nuts and bolts" V&H issues are concerned with quantifying effects such as nuclear-induced attenuation or ground shock vulnerability.

Before discussing these top-level V&H issues, some discussions on how they are developed is in order. Top-level V&H issues are developed in an overall framework of a "top-down" systems approach in which subsystem and component V&H goals are derived from clearly stated objectives of <u>system survivability and endurability</u> (i.e., operability in a nuclear environment). By contrast, a "bottom-up" approach, and one often used in V&H programs, is to

harden subsystems and components to the maximum extent possible within technological and budgetary constraints, and then attempt to "optimize" system-level performance. Either a "top-down" or "bottom-up" approach can be used with success; the top-down approach, however, puts major emphasis on, and clearly illustrates, the trade-offs between hardening and other survivability options (such as redundant links). This is discussed further in the next subsection.

1.2.1 Survivability and Endurability as a C^3 V&H Goal

The suggested focus of the C^3 V&H Program is illustrated in Figure 1-1. In this approach, goals are first established for the C^3 system-level survivability and endurance. These goals should reflect a realism that system performance will degrade in the course of an attack, but that an enduring C^3 system will enable BMD to track targets and launch interceptors so long as tracking and missile assets exist. Stemming from considerations of system-level survivability will be the required overall measure of effectiveness to provide the necessary degree of survivability, and from this performance measure the requirements of C^3 system performance parameters can be derived. (And note that all of these requirements are derived in a top-down fashion from system-level survivability.) At the component/subsystem level, different combinations of availability, reliability, survivability can be examined to provide the necessary performance.

Figure 1-1 can also be used to illustrate a "bottom-up" approach in which the initial focus is on component/subsystem performance. Performance includes such measures as availability, reliability, inter-operability, and the other "ilities." Hardening and survivability are often equated on a one-to-one basis, and the hardening goals might typically be derived from state-of-the-art capabilities. Once the basic subsystem performance parameters are known, the C^3 system parameters can be evaluated; these include such measures as probability of correct message receipt, etc. Analysis of the C^3 system can then be used to establish an overall measure of effectiveness such as connectivity. If this measure is high, then we have some confidence that system performance will be adequate.

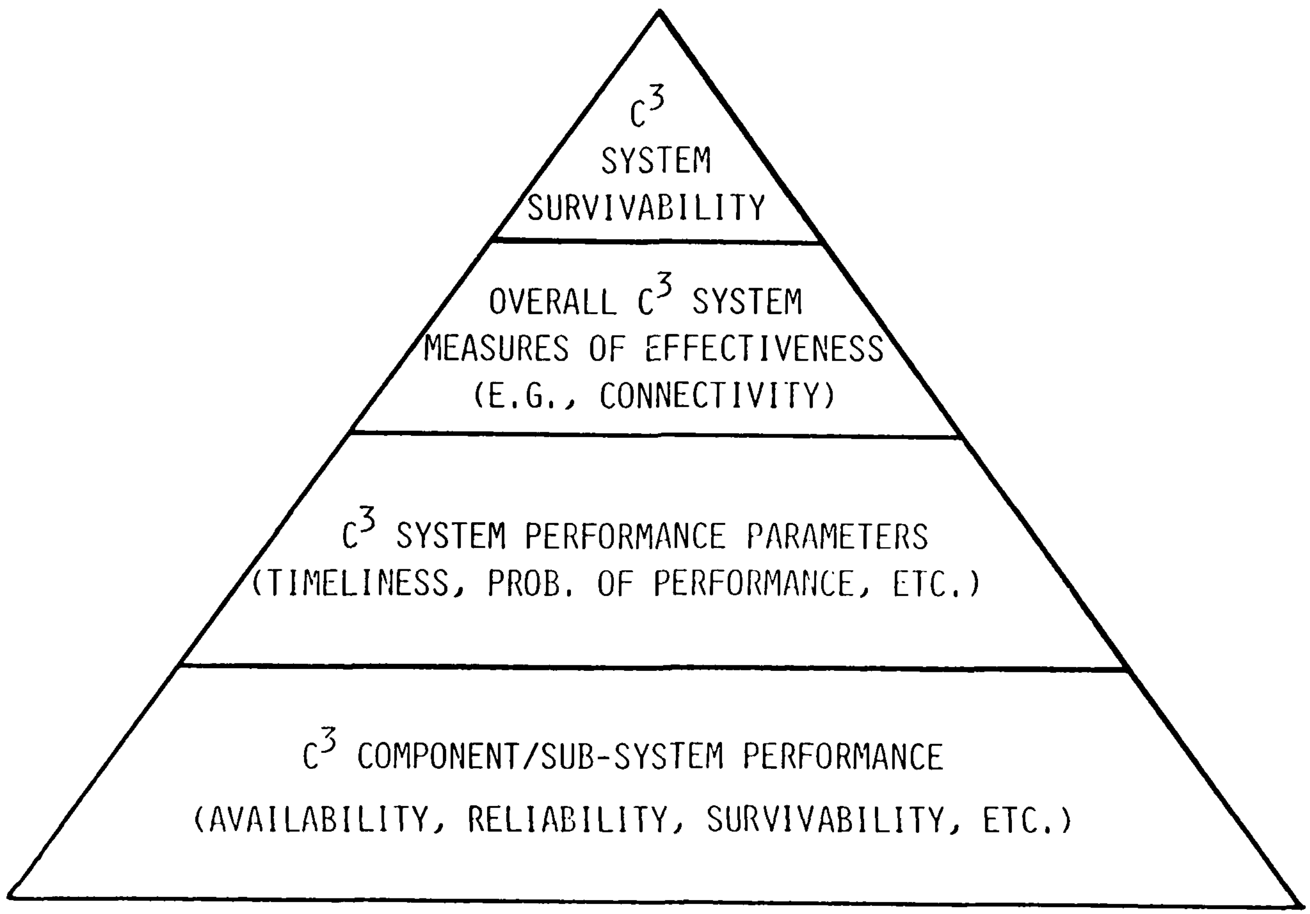

Figure 1-1. C^3 V&H Program with a Focus on Survivability

1.2.2 Impact of a Survivability Focus on a Traditional V&H Program

A top-down approach to organizing a V&H program can still be folded together with the more traditional aspects of a V&H program. Quite simply, a top-down approach puts more emphasis on the early identification of possible C^3 system vulnerabilities and the allocation of resources to correct these vulnerabilities. Implicit in an early identification of problems is the integration of C^3 concerns and the C^3 community with the system design process; the top-down approach will most likely not work satisfactorily if the C^3 system must be designed after the bulk of other system design work is completed.

An overview of how the top-down approach interfaces with a more traditional V&H program is illustrated in Figure 1-2. A typical V&H program will include hardness validation (that the design is indeed hard), hardness assurance (that the system is built and maintained as designed), and hardness surveillance and maintenance (that hardness is maintained for the lifetime of the system). It should also be noted that the system should be designed to facilitate surveillance and maintenance; if life cycle hardness is questionable at any point in this process, other design alternatives should be considered and the entire process iterated.

The details of setting up the traditional aspects of a V&H program, including hardness design, assurance, and maintenance are not included herein. They will be incorporated in the C^3 V&H Program Plan (to be developed).

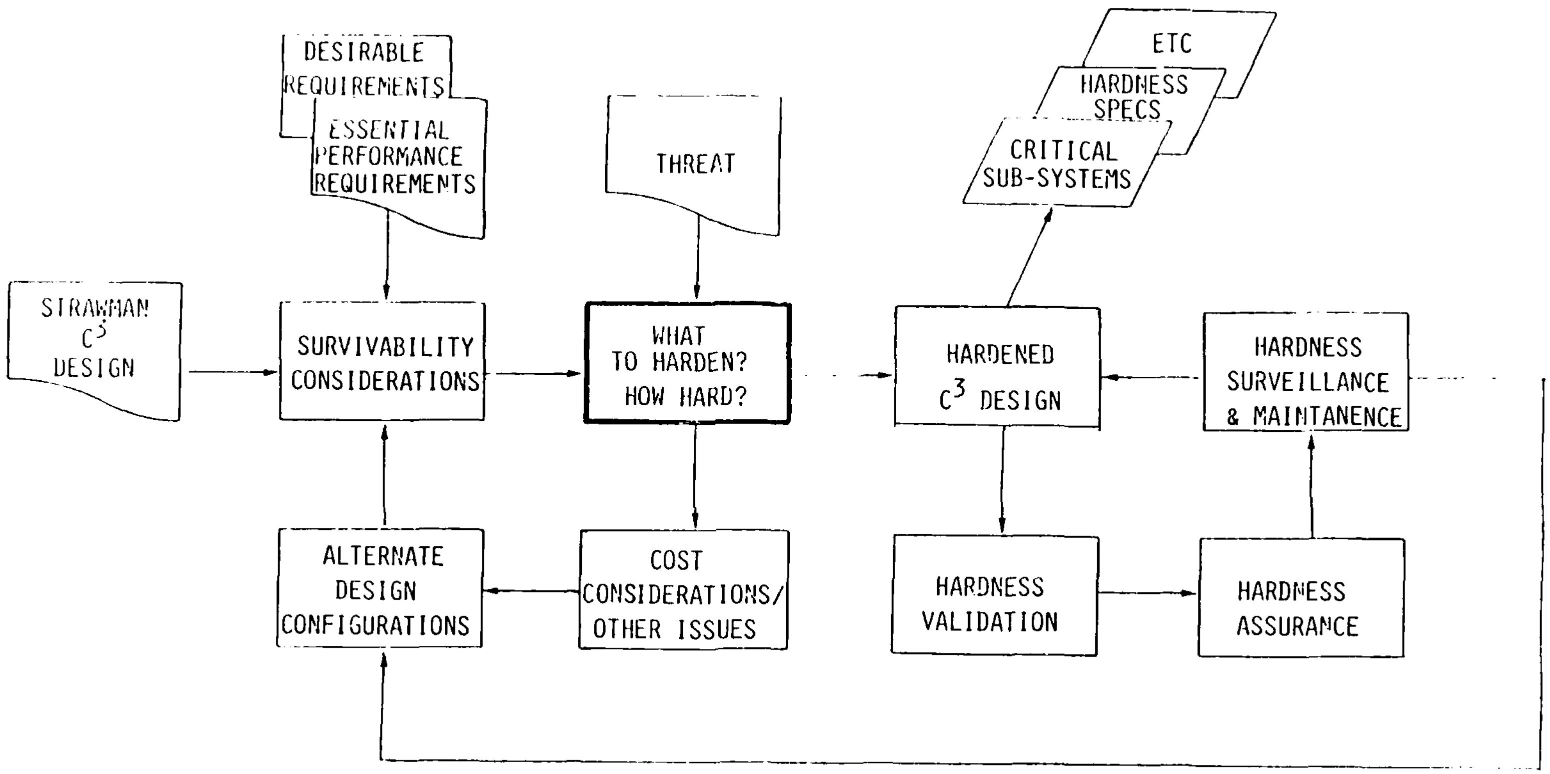

Figure 1-2. Overview of a BMD C^3 V&H Program

2.0 CRITICAL ISSUES FOR A C^3 PROGRAM

The top-level critical issues which are considered in this section are appropriate to any generic BMD system. Second and third tier issues, which get down to specific technical problems, are somewhat dependent on the BMD system design. As a backdrop for developing key V&H issues, it is necessary to make some assumptions regarding those system elements which are tied together by the C^3 system.

These major system elements and their functions are summarized in Table 2-1. The key aspects of the basic system which have an impact on C^3 V&H are:

- Both RF and fiber optics will probably be used for ground-to-ground links.
- Aircraft will probably be part of the baseline system.
- Some interface between BMD and MX will be required.
- The basic concepts for the radar and missile will remain relatively unchanged (basic system building blocks).

2.1 MAJOR ISSUES FOR C^3 V&H

Against this background, some of the major questions which need to be addressed are:

- What is the role of fiber optics as a C^3 link?
  - Is it survivable?
  - Is it affordable?
- What RF frequencies are appropriate for BMD?
  - What frequency band(s)?
  - How reliable are these links?
  - Is RF a primary or backup link for ground-to-ground in the trans-attack period?

Table 3-1. Basic Trends with Respect to Fiber Optic Installation

TENDENCY TO:	DUE TO:	COMMENT
INSTALLATION VIA PLOWING OR TRENCHING	Reduced Excavation Costs	At 8-10' depth of burial, no significant radiation-induced attenuation. Potential vulnerability to ground motion and shock. Temporary link interrupts of small fraction of a second.
	Vulnerability of the Photo Source and/or Detector	Some increased vulnerability in the F.O. cable itself can be tolerated if the photo source (e.g., LED) or photo detector is also vulnerable.
INSTALLATION VIA DEEP TUNNELING	Elimination of Transient Interrupts due to Radiation of the Cable*	V&H emphasis shifts to node vulnerability. Radiation in SEC or SIS may still cause transient interrupt.
	Elimination of Vulnerability to shock and cratering	Integrity of the F.O. cable can be assured at some cost.

*Vulnerability to radiation at the nodes (e.g., LED and photodetector) is still an issue.

- vulnerability of a fiber optic cable as a function of distance from the burst and perhaps as a function of yield
- The vulnerability of the network to cratering and ground motion effects
- the duration of temporary disruption in any link which can be tolerated without undue disruption of the network.

These issues are also of high priority because they may force the system into one of the following:

- use of fiber optics only for peacetime operations (probably an unlikely possibility because of disruption of RF by nuclear effects)
- very deep burial of fiber optics, and the costs must simply be paid.

Regardless of whether fiber optics are either deeply buried or trenched in, it is also necessary to determine the vulnerability of the light sources (e.g., LED) and photo detector. If these elements in the SEC or SIS, for example, are either vulnerable or subject to transient disruption, then some reordering of priorities may be required. For example, radiation-induced disruption on the fiber optic cable itself should be no more of a concern than the disruption at the source or detector.

An overview of how these V&H issues interact with C^3 design issues is shown in Table 3-1. The common demoninator is that a fiber optic cable will probably be installed either via plowing or trenching or by very deep burial; intermediate solutions such as burial at 200 feet appear to embody most of the cost variance with only a small reduction in vulnerability. It is also clear that strong interaction between the C^3 V&H community and the C^3 design community is needed to resolve the unanswered questions on fiber optics.

3.2 ADDRESSING THE SELECTION OF RF FREQUENCIES

All too often the key issues of RF selection are obfuscated by propagation concerns such as absorption, refraction, diffraction, or multi-

3.0 ASSURING ADDRESSAL OF C^3 V&H ISSUES

The previous section addressed those issues which are of major importance from a V&H standpoint and the relationship of V&H issues to design, programmatic, and other key decision issues. This section discusses the verification process to assure that the V&H issues are addressed in a timely fashion. In this verification process, there are two important points to keep in mind:

- Identifying all the technical questions which are related to any given C^3 V&H issue
- Making sure that the myriad of technical details do not obfuscate the key V&H issues.

3.1 ADDRESSING THE ROLE OF FIBER OPTICS

Based upon past and ongoing studies, the following observations constitute a starting point for developing specific V&H action items:

- At very deep burial depths (e.g., 2,500 feet) the fiber optic cable itself is not vulnerable even to ground motion resulting from a surface burst (based on MX studies)
- Excavation costs for deep burial are extremely expensive (cost data bases have been developed for MX)
- With installation via trenching, an 8-10 ft. depth of burial reduces the total nuclear-induced attenuation (permanent effects) to the same level as the intrinsic attenuation; radiation may still cause a transient (fraction of a second) disruption.

For assured survivability, very deep burial would obviously be preferred, but the costs may be prohibitive. A rough estimate of cost, therefore, is of high priority. Concurrent with this is the need to determine some understanding of shallow buried (via plowing or trenching) fiber optic cables, including:

Two other issues are the coordination between the BMD and MX and the coordination between BMD and Higher Authority (HA). Communication links from BMD to MX and from BMD to HA will certainly be included in the baseline system. However, some high-level decisions are needed to provide guidance on how these interfaces will be utilized; this is a necessary prelude to establishing priorities on C^3 vulnerabilities and focusing V&H efforts to correct these deficiencies. For examnle, if a requirement is levied on the system to maintain the interface between BMD and HA throughout the engagement, then the potential vulnerability of the RF link to aircraft, as well as the aircraft themselves, becomes even more important; for increased survivability, ground repeaters may be necessary to enable aircraft to stand off a safe distance, and this could become a major consideration in designing the system.

To summarize, these "other issues" can significantly influence relative vulnerabilities, which in turn influence system design and performance. If progress is to be made in resolving some of these vulnerability questions, then some decisions are needed regarding what is or is not be included in a "baseline concept". These decisions do not necessarily have to be irreversible. The point of all this discussion is that some decisions will be of enormous benefit in focusing the C^3 design and V&H efforts; attempting to study all possibilities before arriving at a decision may be self-defeating simply by opening up too many possibilities.

2.2.3 Interface with Other Issues

A partial list of other major issues is given below. These include:

- Impact of a system IOC on the C^3 V&H
- Division of responsibility between C^2 and the Battle Manager
- Man-machine interface during a battle
- Degree of coordination with MX
- Coordination with Higher Authority (HA).

The principal impact of an IOC is to limit what can be done in a C^3 V&H program. With an early IOC, it may be necessary to utilize GFE as is. In this case, GFE can include COMSEC equipment, computers, and even aircraft. In the absence of an IOC, programs can be established to increase hardness of these components, if necessary, and to tailor their functions more to a BMD application.

One of the major problem areas which has been identified is the division of responsibility between the command and control system and the "Battle Manager." With MDAC responsible for the development of the Battle Manager, and GTE Sylvania responsible for the C^2 system, the functional interface between the C^2 system and the Battle Manager must be clearly defined. Not only do both of these command systems exercise some control over the system, but they will probably also share the same computers. Some consideration has been given to combining the C^2 and Battle Manager functions. Although this would solve some of the functional interface problems, it would at the same time create organizational problems with respect to defining the roles of MDAC and GTE Sylvania. Both the Battle Manager and the C^2 system are closely linked to many of the vulnerability issues, which in turn affects C^3 design. To help prioritize vulnerability concerns (and hence design efforts), some clarification of the Battle Manager and C^2 functions is needed.

optics communications may be limited to peacetime operations, and this will have an impact on system design.

As shown, the vulnerability issues are closely coupled with the programmatic issues. For example, all but one of the C^3 vulnerability issues will influence the system effectiveness evaluation. Lightning, per se, is not shown as a direct contributor to overall system effectiveness, but plays an indirect role if the link interrupts are longer than expected. Propagation losses and the possibility of computer interrupt or upset will be a major interface with the other principal subsystems. Computers are obviously a shared responsibility between the command and control system and the Battle Managers. Propagation losses are an issue in the communications link between the SEC and the missile, even though this part of the communications system is not the responsibility of the C^3 contractor. The major interfaces with other government agencies have to do with the use of aircraft or equipment developed for MX (Air Force coordination) and COMSEC (National Security Agency coordination).

The important point regarding the interface of the C^3 V&H program with other programmatic issues is that C^3 vulnerabilities translate into system-level vulnerabilities, and these need to be thoroughly explored. The potential role of C^3 vulnerabilities in influencing overall system design, and the requirements imposed on the C^3 system by a given system design, needs to be an iterative process. At present, the system V&H program plan does not indicate how the interface with the C^3 V&H program will be established; the following are specific recommendations for inclusion in the system V&H program plan to further define this interface:

- Identification of bounding vulnerabilities to be used in preliminary system definition studies
- Definition of system trade studies to determine the impact of these limiting vulnerabilities
- The rationale for prioritizing C^3 vulnerabilities which are of major concern from a system standpoint.

lightning could be extremely important depending on (1) the frequency of occurrence and noise level (which still needs to be determined) and (2) the RF bands of interest.*

The hardness issues also are coupled to the C^3 design issues, but to a lesser extent. As before, the selection of tolerable delays and interrupts appears to be a matter of highest concern, and is influenced by the nuclear environments.

One notable observation is that the aircraft vulnerability issues are not a significant factor with respect to C^3 design, except possibly from the standpoint of contributing to link redundancy and also from the standpoint of specifying what equipment the aircraft will carry. However, the use of aircraft as part of the BMD baseline has an enormous impact on programmatic issues, and this is discussed in the next section.

2.2.2 Impact on Programmatic Issues

For sake of discussion, the major programmatic issues have been categorized as follows:

- C^3 V&H interface with the system V&H program
- C^3 V&H interface with other subsystem V&H programs
- C^3 V&H interface with other government organizations.

Referring back to Table 2-3, there is some interaction of the hardening issues with the programmatic issues, particularly in the case where the C^3 subsystem elements are located in other subsystem facilities, such as the SEC or SIS. Shock hardening is shown to have an interface with the system V&H program, and this occurs because of the anticipated importance of fiber optic communications to the overall C^3 system; if there are extremely difficult or overly costly problems associated with shock hardening of fiber optics, then fiber

*Current thinking is leaning towards HF, which is where lightning causes major disruption.

issues, (2) programmatic or management issues, and (3) other issues which may require some high-level decisions. The vulnerability issues were extracted as the first tier issues from Table 2-2, and the hardening issues have been organized according to the major C^3 subsystems. Some of the more traditional V&H issues such as EMP, blast, shock, etc. are not mentioned explicitly in the table but are embedded at lower levels, for example, when looking at the hardness requirements of specific components.

2.2.1 Relationship of C^3 V&H Issues to Other C^3 Issues

The entries in Table 2-3 are intended to show the relationships between V&H issues and other C^3 issues. However, neither the V&H issues nor the other C^3 issues are mutually exclusive. For example, the presence of either nuclear or dust-induced lighting will certainly have an impact on the propagation losses on any RF link, and may also affect the duration of any link interrupt. The presence or absence of aircraft will also affect how the system is designed, which in turn has a significant impact on the nuclear environment which may be encountered.

As shown by the number of entries in Table 2-3, vulnerability issues will play a major role in the design of the C^3 system, as might be expected. Based upon the number of vulnerability issues which are identified with each design issue, it is possible to make a first-order prioritization* of the C^3 design issues. For example, it is seen that particular attention needs to be given to link redundancy and to determining tolerable delays and interrupts which the C^3 system can sustain without serious disruption of the entire BMD system. From a vulnerability perspective, it is clear that understanding RF propagation losses is crucial to the C^3 design process because it affects so many of the design concerns. Similarly, the issue of nuclear/dust induced

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* A word of caution is also in order. Because the organization of the issues is somewhat subjective, as are the entries in the matrix, counting the number of issues identified under each C^3 design issue is also a subjective means of establishing priority.

Table 2-3. Relationship of C^3 V&H Issues to Other C^3 Issues

	DESIGN ISSUES	NETWORK PROTOCOL	DATA RATES	USE OF REPEATERS/RELAYS	LINK REDUNDANCY	POP-UP VS. HARD ANTENNAS	TOLERABLE INTERRUPTS/DELAYS	SIGNAL MARGINS	COMPUTER RELOAD CAPABILITY	PROGRAMMATIC ISSUES	C^3 V&H INTERFACE WITH SYSTEM V&H	C^3 V&H INTERFACE WITH SUBSYSTEM V&H	C^3 V&H INTERFACE WITH OTHER GOVERNMENT ORGANIZATIONS	OTHER ISSUES	IMPACT OF AN IOC ON C^3 V&H	DIVISION OF RESPONSIBILITY BETWEEN C^2 AND BATTLE MANAGEMENT	MAN-MACHINE INTERFACE DURING BATTLE	DEGREE OF COORDINATION WITH MX	COORDINATION WITH MA
SURVIVABILITY ISSUES																			
RF PROPAGATION LOSSES			●	●	●	●	●	●			●	●				●	●	●	●
SHOCK VULNERABILITY OF FIBER OPTICS					●													●	
NUCLEAR/DUST LIGHTNING			●		●		●	●								●	●	●	
DURATION OF LINK INTERRUPTS		●	●		●		●				●					●	●	●	
USE OF C[illegible]EC		●					●				●		●		●			●	●
COMPUTER RESET		●	●				●		●		●	●							
AIRCRAFT BASE ESCAPE											●		●			●	●		●
AIRCRAFT SURVIVABILITY											●		●			●	●		●
AIRCRAFT ON-STATION TIMELINESS					●						●		●			●	●		
HARDENING ISSUES																			
FIBER OPTIC HARDNESS			●		●						●								
ANTENNA HARDNESS						●													
COMPUTER HARDNESS							●		●			●							
TRANSCEIVER HARDNESS					●							●							
FACILITY SHIELDING							●					●							

Table 2-2. Key V&H Issues Under Top-Level Issues

TOP LEVEL ISSUES	V&H SUB-ISSUES
1. What is the role of fiber optics as a C^3 link?	• Nuclear Induced Attenuation --Signal Interrupt --Protection by Deeper Burial • Shock/Ground Motion Vulnerability • Source/Photo Detector Vulnerability • Hardening Options --Fiber Optic Cable --Source/Photo Detector
2. What RF frequencies are appropriate for BMD?	• Propagation Uncertainties --Attenuation --Antenna Hardness --Diffraction --Distortion • Nuclear/Dust Induced Lightning • Expected Link Interrupt
3. What is a realistic role for aircraft?	• Base Escape • Survivability/Endurability • Timely Station Attainment • Vulnerability of the Manned Interface
4. To what extent can (must) existing hardware be utilized?	• Vulnerability of Current/Planned COMSEC • Vulnerability of other "Off-the-Shelf" Equipment • Effectiveness of Shielding
5. What is the impact of MX coordination on C^3?	• Message Rate Requirements • Pre-Planning for Later BMD Deployment • Quality of the Threat Characterization
6. How can system turn-on be assured?	• Survivability of Long Distance Links --Satellites --Aircraft/Airborne Relays • RF Propagation --Reflection By Perturbed D-layer --Meteor Scatter & Adaptive HF/VHF

The last major issue which is of current concern is the coordination of BMD with MX. This poses many problems, including the possible sharing of communication links and the impact on message data rates, putting BMD elements (possibly the System Battle Manager) on the ALCC, and the message traffic between BMD and MX. There is also the question of trying to design MX today to accommodate future deployment of BMD, and this poses difficult planning tasks of interfacing the two systems now, at reasonable costs, without adversely constraining future design enhancements to BMD.

At first glance it would appear that these major issues are not really C^3 V&H issues, at least in the traditional sense of worrying about blast, shock, EMP, TREE, etc. (vulnerabilities) of the C^3 links and nodes, and possible means of hardening against these effects. However, under each of these major issues are a number of second tier issues which do start to have a V&H flavor. These second tier (and in some cases, third tier) issues are shown in Table 2-2. However, it should be noted that the second tier issues under MX coordination do not directly pertain to either vulnerability or hardening. The subject of "message rate requirements" is a design issue; the subject of pre-planning involves both design and programmatic issues; the subject of "threat characterization quality" is a system effectiveness issue. All will eventually have an impact on how the system is designed, and there will certainly be V&H questions on the design.

The above discussion points out the need for some means of categorizing all the issues which will have to be addressed by the C^3 community into those of primary importance from a V&H perspective, of primary importance from a design perspective, of primary importance from a system perspective, and possibly other viewpoints.

2.2 RELATIONSHIP OF C^3 V&H TO THE TOTAL C^3 SYSTEM

One possible categorization of C^3 issues is shown in Table 2-3; the entries on the left are the key vulnerability and hardening issues, and the entries along the top represent other issues of importance to the C^3 community. These other issues have been divided into categories of (1) design

The aircraft themselves are major issues; airborne elements might include optical adjunct (OA) aircraft, relay aircraft (also containing the System Battle Manager), and possibly even shared utilization of the Airborne Launch Control Center (ALCC) between BMD and MX. Continuous airborne aircraft, which eliminates the vulnerability to a surprise SLBM attack, are extraordinarily expensive to operate. The alternatives are base alert or strip alert, both of which pose problems of base escape and timely arrival on station. However, even if the aircraft are on station at the start of a BMD engagement, there are questions on how long they will survive (endure), and even if they do survive and endure, can they communicate back to the BMD ground elements in a timely fashion. These are crucial questions, and need to be addressed now.

Another major issue is the use of existing equipment. From a pragmatic standpoint, essentially all the C^3 equipment, including transceivers, computers, antenna, etc. will probably be assembled from off-the-shelf components; where new designs are required, they will probably be more of an evolutionary change. However, COMSEC gear (encryption devices, decoders, etc.) could pose some special problems, and is therefore of particular concern. Because the COMSEC is the responsibility of the National Security Agency, specifications for any new COMSEC gear need to be established early, and are probably not amenable to significant change. Consequently, there is pressure to use existing COMSEC or the COMSEC that is currently under development (as for MX).

Still another major issue is assuring that the system can be turned on; i.e., that timely nuclear release is achieved. Once a nuclear war starts, long-range communication will always be in jeopardy because of high altitude bursts (perturbation of the D-layer), or loss of satellites, or loss of airborne elements. A similar (but maybe not as critical) problem is turning the system off. A portion of this problem is related to the selection of appropriate RF frequencies, but of greater concern is establishing sufficient redundancy to preclude the simultaneous loss of all long-distance communication links.

- What is a realistic role for aircraft?
  - Are survivable aircraft elements affordable?
  - Will BMD work without the airborne elements?
- To what extent can (must) existing hardware (transceivers, computers, COMSEC, etc.) be utilized?
  - Is it suitable?
  - Is it sufficiently hard?
  - Are new designs feasible?
- What is the impact of MX coordination on C^3?
  - Can resources be shared?
  - What price do we pay now to add on BMD later?
- How can system turn-on be assured?
  - Survivability of communication links to Higher Authority (HA)?
  - Pre-delegated release authority?

From a top-down systems approach, these are the major issues by which C^3 concerns affect system-level concerns, and vice versa. Fiber optics represent a relatively new technology which offers significant potential, especially in terms of high quality data transmission rates, but at the same time represents a potential vulnerability (unlike RF, a broken fiber optic link does not recover). If buried deep enough, fiber optics will certainly survive, but the cost may be prohibitive. For MX, the current thinking is that fiber optics will be employed for peacetime operation, but will not be counted on during a wartime situation. A similar philosophy may be adopted for BMD.

The question of what RF frequencies are appropriate for BMD is extremely complicated and involves issues of message rates, diffraction, absorption, antenna hardness, and many other concerns generated by a nuclear environment. In addition, with an aircraft element in BMD there are questions of range, antenna vulnerability to EMP, on-board power requirements, etc., all of which have a bearing on the selection of RF frequency band(s). It should also be noted that the preferred RF frequencies may be in the commercial broadcasting bands, which would be a severe limitation on using RF for peacetime operations.

Table 2-1. BMD C^3 Elements and Functions

ELEMENT	MAJOR FUNCTIONS
Higher Authority	• System Activation • Nuclear Release • Status Collection • Offense/Defense Coordination
Defense Control Center	• Day-to-Day Control of Radar/Launchers/ Interceptors (Status/Maintenance/ Interrogation/Logistics/Test) • Offense/Defense Coordination • System Activation • Battle Management
SENTRY Interceptor System (SIS)	• Receive and Act Upon Nuclear Release/ Weapon Unlock/Launch Commands • Respond to Interrogations • Report Status
Sensor & Engagement Controller (SEC)	• Convey Nuclear Release to Interceptor • Control Interceptor Launch • Relay Data to/From Interceptor • Perform Launch/Battle Management (Fire Control) • Surveillance, Track and Report Incoming Targets • Report Status
Forward Surveillance Systems (Optical Adjunct or Forward Radar)	• Surveillance, Track and Report Incoming Targets • Relay Data • Report Status

path. This occurs in part because of the complex nuclear phenomenology that is needed to evaluate and quantify these effects. However, it is important to keep in mind that these are nuclear-induced effects and should be considered in the aggregate. This aggregate should include not only the nuclear environment effects on propagation, but also antenna vulnerability and system requirements such as message rates or propagation ranges. As an illustration of how these considerations can be lumped together, Table 3-2 illustrates that the net effect of all these concerns can drive the C^3 system to either higher or lower frequency bands.

Table 3-2 also indicates that there can be conflicting desires in selecting an appropriate RF frequency, and no single frequency band will be capable of mitigating all adverse nuclear effects. Again, this reinforces the need to consider all effects and constraints in the aggregate and to arrive at a compromise that is in the best interests from a system-level perspective.

It is possible, however, to establish some bounds. For example, message rate requirements define a lower frequency bound. Message rate requirements should include not only the message traffic for BMD operations, but also allowances for:

- Two-way HA message traffic
- Two-way traffic with MX
- Possible growth options for the above
- Some degree of link interrupt.

Concern for antenna survivability may also establish an upper frequency bound, for example, if buried antennas are essential for survivability. This bound is probably not a rigid bound because hardened pop-up antennas are also feasible. (Note: if this upper bound is not above the lower bound dictated by message rate requirements, then only pop-up antennas should be included in subsequent V&H studies.)

Table 3-2. Basic Trends for RF Frequency Selection

TENDENCY TO:	DUE TO:	COMMENT
HIGHER RF FREQUENCY	Reduced blast and shock vulnerability of exposed antennas	For frequencies of VHF and higher, buried antennas probably not possible.
	Message rate requirement	Message rate requirements set a lower frequency bound.
LOWER RF FREQUENCY	Dust attenuation	Probably not a major problem, but will add to signal margin.
	Ground wave propagation	Probably not a limiting factor for BMD.
	Use of burried antenna	Antenna survivability a strong argument for HF or lower.
	Diffraction over craters	Essential to diffract over craters with sufficient signal margin to compensate for attenuation.
	Diffraction around fireballs	May be possible in some cases. It may be difficult to establish confidence in diffraction as a means of maintaining connectivity.
EITHER HIGHER OR LOWER RF FREQUENCY	Nuclear or dust-induced lightning	RF noise created by lightning is most prominent in the HF band.

3.3 ASSURING A REALISTIC ROLE FOR AIRCRAFT

Most of the aircraft survivability data base developed for MX will be directly applicable to BMD, including:

- basing
- costs
- EMP vulnerability studies.

V&H efforts should focus on the unique aspects of BMD aircraft. These unique aspects include:

- vulnerability of the LWIR equipment
- vulnerability introduced by mission profiles to maintain essentially continuous connectivity with the ground elements
  - OA aircraft
  - Relay aircraft (possibly housing the Battle Manager)
- probably reduced requirements on endurance, but higher requirements on survivability
- message rate requirements
  - OA aircraft
  - Battle Manager.

However, before such V&H efforts are undertaken, some decisions, possibly based on the aircraft studies for MX, are needed to pin down <u>if</u> aircraft will be used and <u>how</u> aircraft will be used. Also influencing these decisions are other high-level decisions concerning the degree of coordination with MX and HA, and the man-machine interface as part of BMD. These issues are discussed in Section 3.5.

3.4 ASSURING TIMELY SYSTEM TURN ON

There are three major areas which need to be addressed to assure timely nuclear release and system turn on:

- policy decision regarding who has release authority
- vulnerability of RF nodes broadcasting the releasing authority
- RF propagation.

Of the above topics, only the last will require C^3 V&H efforts under the BMD program. The question of who has release authority is strictly a policy decision. Nuclear release authority normally resides with the National Command Authority (NCA); however, there is a precedent for vesting release authority at a lower echelon. With respect to the vulnerability of RF nodes, the survivability of these national assets (ground terminals, satellites and airborne aircraft) is well documented in past and ongoing studies. From the standpoint of the BMD system, a reasonable assumption is that nuclear release will be issued (by whom is not important) and broadcast from surviving national assets, and possibly transmitted over land lines as well. The impact on BMD V&H is to insure that the message is received and acted on.

RF propagation is therefore a C^3 V&H issue. However, this aspect of RF propagation differs from that previously discussed in the following ways:

- less emphasis on the maintenance of connectivity after nuclear release is received
- more emphasis on very long links back to the releasing authority.

The first bullet relaxes some of the concerns regarding temporary disruption of RF links; it is more important to assure system turn-on than to maintain communications between BMD and HA. The second bullet puts more concern on HF disruption via D-layer absorption, because a high altitude burst may be the first confirmation of hostilities. Fortunately this is one of the most studied nuclear weapons phenomena, and the existing data base should be adequate.

Another technology which might be examined for BMD applications is meteor burst communications. Nuclear detonations create significant ionization which may actually enhance meteor burst communications, and will to some

degree compensate for the disruptive effects of D-layer absorption. Meteor burst communications is being investigated for MX, and these efforts should be expanded for BMD applications.

3.5 AREAS REQUIRING PROGRAMMATIC DECISIONS

Other top-level issues concern the use of existing hardware (especially COMSEC) and the impact of MX coordination. The key to resolving these issues does not reside directly in the C^3 V&H, but rather in obtaining some high level decisions to resolve some basic questions. These problem areas are discussed below.

3.5.1 Does BMD Have an IOC?

At present, a near-term BMD system does not appear likely. From a C^3 perspective, this is probably advantageous because, if a near-term IOC is specified, there are major constraints imposed upon the C^3 system, including:

- C^3 equipment will have to be predominantly "off-the-shelf" equipment and will have to be shielded against the expected environments in these facilities. Redesign of hardened equipment will probably not be feasible.
- A survivable C^3 system will be overdesigned to compensate for unknown vulnerabilities. The C^3 system will probably be over-specified, both in the number of types of communications links employed (fiber optics, HF, LF/VLF, etc.) and in the number of redundant links between any two nodes.

This will result in a C^3 system which is:

- Very expensive
- More complex than necessary and probably less reliable than desired
- Of unknown confidence with respect to survivability.

An intermediate IOC, perhaps in the early 1990s, appears more likely, and it should be possible to resolve some of the major uncertainties, including:

- The shock vulnerability of buried fiber optic cables
- Approximate bounds on multiburst environments
- The utility and/or vulnerability of aircraft as part of the C^3 system.
- Impact of nuclear/dust lightning
- Approximate quanitification of the contribution of C^3 to total system effectiveness.

If the IOC is very distant (or not specified at all), then all of the above plus second-order uncertainties could either be resolved, or at least better understood. More importantly, the additional time would allow multiple interactions between the BMD system designers and the C^3 system designers, which would produce a C^3 that is tailored to the BMD system from the standpoint of system-level survivability and endurability. Schedules and milestones are discussed in greater detail in Section 5.

3.5.2 Interface of HA to BMD

The role of higher authority has a bearing on the definition of the man-machine interface, which in turn has a bearing on how the interface between the C^3 system and the Battle Manager is defined. Therefore, the role of higher authority in the definition of C^3 requirements should be defined first. There are several aspects of the higher authority interface including:

- Nuclear release authority
- Withdrawal of nuclear release authority
- Modification of the engagement philosophy or tactics.

A crucial requirement of any BMD system is a timely turn on of the system and the granting of nuclear release authority. Withdrawal of nuclear release authority can also be of major concern, particularly if there is no man-machine interface to modify engagement tactics. For example, if in the conduct of a BMD engagement it appears that the system is not working correctly, there could conceivably be a human decision to launch MX even in the presence of an attack. If there is no provision to modify the battle management philosophy being followed by the Battle Manager, the only way to accomplish this would be to essentially turn the system off. If there is interaction between human beings and the Battle Manager, then the requirement to withdraw nuclear release authority is probably less pressing, but preservation of the man-machine interface is all important.

3.5.3 Definition of the Man-Machine Interface

Current thinking is that the Battle Manager, once turned on, will be a completely automated system and function autonomously until turned off. This is an area that deserves additional thinking, not only from the political standpoint of attempting to design a truly "fail-safe" system, but also from the standpoint of V&H concerns which include:

- Computer upset
- Link disruption
- V&V (verification and validation) of large complex software that comprises the Battle Manager.

3.5.4 The C^2/Battle Manager Interface

The current division of responsibility between the Battle Manager and the C^2 system is based upon functional responsibility. The Battle Manager is responsible for the conduct of a BMD engagement, including:

- Threat characterization
- Assignment of BMD resources, including radars, missiles, and distributed battle management functions

- Engagement planning
- Launching of missiles to engage threats
- In-flight updates
- Status monitoring

The C^2 system would be responsible for all other command functions, including:

- Status monitoring and reporting
- System turn on and turn off
- Coordination with MX (under Battle Manager control)
- Selection of message routes
- Encryption/decoding
- Monitoring of message traffic and selection of priority messages.

Although there is a functional division of responsibility, both the Battle Manager and the C^2 system will share the same communications network, the same transmitters and receivers, and the same computers. Stated another way, the division of hardware responsibility is out of synchronization with the division of functional responsibility. As previously discussed in Section 2.3.3, some decisions on this interface are needed.

There are still other interface and coordination problems, and these are discussed further in the next section.

3.6 INTERFACES AND COORDINATION

3.6.1 Interface with the National Security Agency

It is NSA's responsibility to design and oversee the development of all COMSEC equipment. For application to BMD, there are three primary options:

- Initiate a request to NSA to development COMSEC gear that is hard to a specified level of nuclear environment
- Use existing COMSEC gear and provide adequate shielding to ensure that current hardness levels are not exceeded. These hardness levels will have to be provided by NSA
- Use existing COMSEC gear and include a provision to circumvent the COMSEC gear in the event of equipment failure. The C^3 system would then have to be designed to shift from an encrypted message format to a non-encrypted format.

The last option is probably of interest only if the IOC is near-term. The last two options would add to the near-term priority of adequately specifying the environments in the SEC and the SIS. If a far-term IOC is specified (or not specified at all), there are some definite advantages to developing a new series of COMSEC gear. It could probably be made harder than current equipment, and it could also be specifically tailored to BMD applications.

3.6.2 Interface with the Air Force

If an optical adjunct, or aircraft relays, and/or an airborne command post is included as part of the BMD system, there will be a strong need to interface with the Air Force. Even with a far-term IOC, it is unlikely that BMD requirements would have a significant impact on the development or the hardness of the aircraft. The development timelines for any new aircraft are extremely long as is an aircraft hardening program. As a result, the BMD system will probably have to live with whatever aircraft can be provided by the Air Force (if an aircraft is utilized). Where BMD requirements can have an impact is with respect to the number of aircraft required, where they are based, and the onboard C^3 equipment.

There has been some consideration given to providing an airborne defensive operations center on the MX Airborne Launch Control Center (ALCC). However, the current baseline ALCC aircraft for MX is a derivative of the Boeing 707, and there is probably insufficient room and carrying capacity to also accommodate BMD communications equipment. Consequently, if it is decided to merge the airborne DCC and the ALCC functions on a single aircraft, such a

decision needs to be made sooner rather than later in order to specify an adequate size aircraft (such as a derivative of the Boeing 747).

The other major interface with the Air Force is with respect to MX coordination. As discussed in the previous section, there is a coupling between the C^3 vulnerability issues and the degree of MX coordination. However, the linkage is such that policy decision are the dominant factors and will influence the relative priorities of C^3 V&H issues, and not the other way around. This is but one more example of the need for high-level decision to initiate future V&H activities.

One possibility which probably deserves more attention is the use of remotely piloted vehicles (RPVs) or airborne relays. These might be either temporary relays to be used until the relay aircraft are on station, as backups to relay aircraft if they are destroyed, or even used in lieu of relay aircraft. The RPVs might be supplied by either the Air Force or the Army; if Air Force supplied, the interface requirements would be similar to those for aircraft.

4.0 TOOLS NEEDED FOR VERIFICATION OF A V&H PROGRAM

4.1 C^3 EVALUATION

The evaluation of the vulnerability and hardness of the BMD C^3 system design, and the feedback of that evaluation to influence the design, can involve a large number of analyses and test procedures spanning a wide range of technologies. Over the past several years a number of computerized analysis tools have been developed to aid BMD systems designers. Many of these computer programs have application for V&H studies of other system components as well as C^3 (such as radars and interceptor farms). In the discussion below, the kinds of analyses that need to be performed for design verification are listed and grouped into subject categories. The emphasis is on computer programs and analysis methodologies for V&H program verification purposes; the role of the fabrication technique, parts selection, quality control, testing, and other related disciplines is not considered here.

4.1.1 Nuclear Environment Calculations

Nuclear environment calculations are essential to a V&H analysis. Table 4-1 lists the most important nuclear environments with a short comment about the availability of computer programs to calculate each environment. In this terminology, a "systems-level" code is one whose detail and accuracy are adequate as starting points for component response analysis, but computer run time and requirements are moderate. There are some deficiencies in our understanding of these phenomena which are reflected in the lack of computer program coverage of these areas. Furthermore, some of the calculations require data about the site before really meaningful calculations can be made. Table 4-1 also lists some typical free-field programs that have been used in past studies and summarizes some of the shortcomings of computer tools for each environment.

Table 4-1. Status of Nuclear Environment Calculational Programs

ENVIRONMENT	STATUS OF CALCULATIONAL TOOLS	TYPICAL PROGRAMS	DEFICIENCIES NOTED
Airblast	• Good systems-level codes available • Multiburst calculations can be made	1-KT Blast Std. SPARK LAMB	• Blast precursors uncertain • High overpressures (>1000 psi)
Ground Shock	• Large codes, complex calculations	CRAM HELP	• System-level code needed • Details are site-specific
Thermal Radiation	• Good systems-level codes available outside fireball • Large complex codes for fireball interiors	SNARE KNFIRE	• Systems-level fireball code needed • Phenomenology and computer tools outside fireball are in good shape
Nuclear Radiation	• Good systems-level codes available • Strong weapon output dependence	ATR IDEA MORSAIR	• Phenomenology and computer tools are in good shape
High Altitude EMP (HEMP)	• Few systems-level codes • Worst-case envelope specification usually employed in analysis	EMPFLD	• First principles calculations are very complex • Systems-level code needed
Near-Ground Burst EMP	• Complex calculations required • Subsumed by HEMP specifications except very near burst point		• Systems-level code needed
Cratering	• Simple scaling relationships are available • Calculational uncertainties remain large		• Details are site-specific MX procedures should be followed
Debris	• Simple scaling relationships are available		• Details are site-specific
Dust Clouds	• Some systems-level codes available • Not damaging to BMD C^3 components	VORDUM	• No additional requirements for physical damage evaluation
Nuclear Cloud Lightning	• No computer simulations yet		• No models available • EM noise source is still uncertain

4.1.2 C^3 Node Damage

Communications networks are typically modeled as a collection of nodes and links, where nodes represent locations where messages originate, are relayed, or are received and used. Typical equipment at a C^3 node may include RF transmitters and receivers; cable or land line transmitters and receivers; computers and data processing equipment; cryptographic and error-correcting encoding and decoding equipment; sensors and status indicators, and RF antennas. These C^3 components are usually part of the installation they serve, such as a radar or interceptor silo. A vulnerability assessment of the overall structure response to air blast, ground shock, thermal radiation, and debris environments would generally be performed independently of the C^3 functions of the facility. Additional response calculations for these environments will be needed for certain types of C^3 equipment such as antennas and antenna connections, cable connections, and some C^3-related sensors. C^3 equipment mounting and shock environment survival must also be examined for each piece of equipment. Since essentially all C^3 components are electrical equipment, a separate study must be made of system and component response to EMP, nuclear radiation, and nuclear cloud lightning.* For completeness, the power supply survivability must also be determined either as part of the C^3 analysis or during the course of the overall facility evaluation.

Ground facility damage response calculations are specific to a particular system design and generally involve complex computer modeling. The system must be described in sufficient detail so that the free-field environments can be applied to the structure or equipment in a meaningful way. The data collection requirements for representing the system usually dominate the computer code analysis process. Fortunately, most of the relevant material and electrical properties needed for these calculations have been collected in handbooks or data tapes. Table 4-2 lists some of the more important C^3 node

*As well as ordinary lightning.

Table 4-2. Illustrative Examples of C^3 System Response Calculations to Damaging Environments

1. Free-Field Environment:	Ground shock acceleration and displacements
System Response Example:	Verify the integrity of a transmitter mounting
Data Needs:	• Transmitter size, weight, and weight distribution • Shock mount elastic properties and travel limits • Shock mount yield and ultimate strengths
2. Free-Field Environment:	Ground motion
System Response Example:	Verify buried cable survival at the entry point to an interceptor silo
Data Needs:	• Cable tensile strength • Burial depth and surrounding geology • Cable configuration near silo entry point • Earth/cable coefficient of friction • Cable penetration design
3. Free-Field Environment:	EMP
System Response Example:	Compute current time history at a receiver power supply cable for design of EMP tests
Data Needs:	• Receiver mechanical layout and positioning • Power supply cable routing • Cable pentration design details • EMP surge arrestor and other hardware performance data • Cable termination parameters
4. Free-Field Environment:	Nuclear Radiation
System Response Example(A):	Determine radiation environments at a hardened tape drive inside a Support Equipment Vault
Data Needs:	• Geometric model of the facility • Material (elemental) composition of facility component parts • Neutron and gamma ray cross section library
System Response Example(B):	Determine TREE effects on a hardened tape drive
Data Needs:	• Circuit diagram • Piece parts identification (detailed) • Piece parts radiation response data or estimates • Normal operating parameters and tolerances
5. Free-Field Environment:	Thermal Radiation (Fireball Exposure)
System Response Example:	Whip Antenna temperature history
Data Needs:	• Antenna design • Antenna materials and coatings • Heat conduction coefficients

5.2 V&H INTERFACES

In addition to the C^2/Battle Manager interface, the principle interfaces with the C^3 V&H activities have to do with (1) the nuclear environments in the SEC, SIS, and other facilities housing C^3 equipment, and (2) the system V&H program. Much of the C^3 equipment is obviously electronic, and there is a tradeoff to be made between hardening the equipment and/or increasing the radiation shielding afforded by the facility. The costs and problems and confidence of providing shielding need to be balanced against a similar set of concerns on equipment hardening. There is also the need to integrate the C^3 V&H with the system V&H; for example, major efforts to reduce C^3 vulnerability should produce a corresponding improvement in system effectiveness.

5.3 MAJOR MILESTONES

Not shown in Figure 5-1 are a number of key decisions which will have a major impact on how a BMD system might be designed, and consequently on how a V&H program might be structured. These were discussed in Section 3.5; to briefly review, some of the key unanswered questions that remain are:

- where is the manned interface?
- will an exo-atmospheric capability be part of the system?
- is an optical adjunct to be included?

A number of proposals have been suggested, but some decisions on these most basic questions are needed. Again, the importance of some decisions on fundamental concepts is emphasized; these are crucial to the development of a C^3 system in general, and a V&H program in particular.

For the V&H efforts pertaining to fiber optics, there are two major milestones prior to developing a baseline fiber optic network and the associated performance data base. These are:

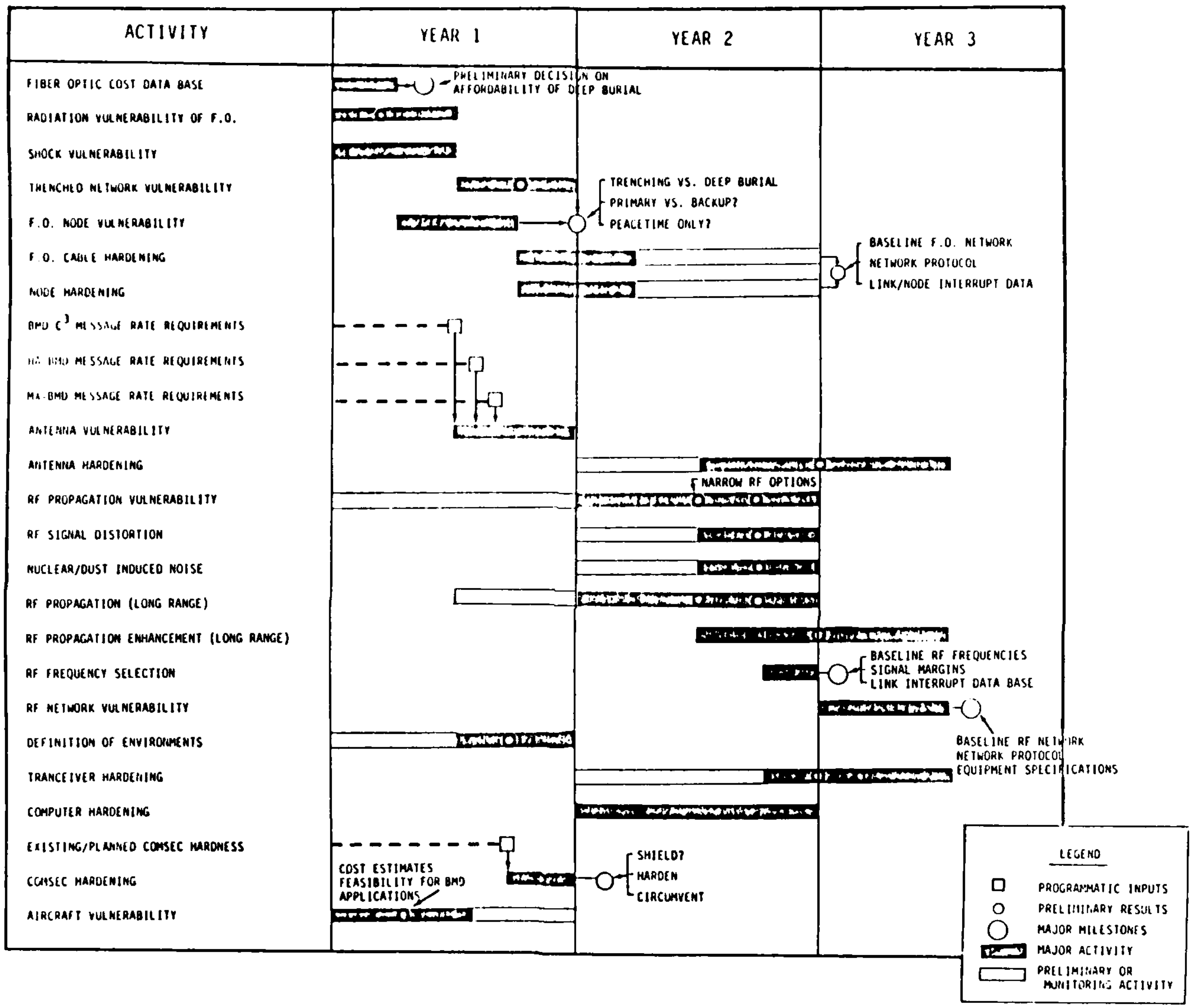

Figure 5-1. Schedule and Milestones for C^3 V&H

5.0 SCHEDULES AND MILESTONES

An overview of the schedules and milestones for the C^3 V&H activities is shown in Figure 5-1. This schedule includes only those activities which are part of a "top-down" approach to C^3 design; many of the traditional aspects of a V&H program such as EMP and TREE analyses, are conducted after hardware designs are available.

5.1 SCHEDULE CONSTRAINTS

The schedule shown is not constrained by a system IOC. However, there are some other constraints. First, there are programmatic inputs with respect to HA and MX coordination which are needed (in addition to a C^3 architecture for BMD) to define message rate requirements, which is a key driver in the vulnerability analyses of the RF network(s). It should also be noted that high-level decisions regarding how and when messages are sent between BMD and MX and BMD and HA are also a necessary prelude to the V&H of COMSEC gear.

Between the two major building blocks of fiber optics and RF propagation, RF propagation will dominate the V&H efforts. Not only are there more specific topics to evaluate purely from a propagation standpoint, but also there are more topics which are logically evaluated in sequence; hence, the timelines are somewhat longer.

The computer hardening efforts can be accomplished at almost any point in the program after computer sizing is complete and the nuclear environments are specified. The principle constraints on the computer hardening efforts will be the coordination between the C^3 system and the Battle Manager; as previously discussed, there are probably more problems with making certain that the C^2 and Battle Manager functions work together than with any actual hardening of the computer.

point during the attack. The timing of this failure will depend on the scenario as well as the C^3 node or link hardness. The measures of system effectiveness, such as the number of MX missiles saved, can be evaluated both with and without this C^3 failure and a semi-quantitative estimate made of the value of C^3 system survivability improvements. By extending this kind of analysis to other C^3 system components and other scenarios, a broader perspective of the C^3 V&H activity usefulness can be developed.

There are a limited number of ballistic missile defense simulations that could be useful for a C^3 system evaluation. One of these is the RING code, developed by McDonnell-Douglas over a period of several years and now being applied to BMD. RING is primarily a radar/missile/RV engagement simulation; documentation of the most recent version is now in draft form. A second large scale BMD simulation is the ENDOSIM program, developed by the Honeywell Corp. for the BMDATC Missile Directorate. ENDOSIM emphasizes non-nuclear kill missile operations and does not include C^3. Both RING and ENDOSIM are operational, although upgrades and modifications continue to be made. Still under development by Teledyne Brown is the BMD Defense Module Simulation (DMSIM). A provision is being made for a C^3 model in DMSIM, but the initial implementation of this model will handle only communications between the sensor and engagement controller (SEC), and the interceptor subsystem. Finally, the Multiple Engagement Model (MEM), developed by Science Applications, Inc. simulates the operation of an enhanced Soviet BMD system with both Spartan-like and endoatmospheric interceptors. MEM includes a radar and interceptor farm netting model which can experience random reliability failures during an engagement. Adding or upgrading the C^3 modeling in one of these simulations to model BMD C^3 explicitly would provide a tool with capability to provide a great deal of insight into the value of C^3 to BMD.

links are primarily for peacetime operation; others must be made survivable if the system is to function properly during the trans-attack period of a nuclear strike. Some aspects of C^3 system operation are of obvious value to system operation; e.g., the link to Higher Authority allows the decision to engage to be passed to the system. The value of other links, and the value of link survivability, are often less apparent. The C^3 contribution to overall BMD effectiveness is difficult to evaluate, particularly as a function of link purpose and hardness. For instance, if a Long Range Radar (LRR) is deployed with BMD, how valuable is the link from that radar to the BMD Battle Manager? And how does that value change with time--is this link still needed after BMD autonomous operation begins? Are there still functions the LRR can perform (if it is not destroyed) as the attack on MX and BMD develops? These kinds of questions must be answered before the contribution of this link to overall performance can be deduced.

There are several ways the C^3 contribution to BMD performance can be evaluated. One of the most commonly employed techniques is the use of engagement simulations. A good BMD simulation will predict, for a given set of scenario conditions, the outcome of an engagement between the defense and the attacking RVs. Various measures of merit are used to evaluate this outcome; these can include the number of RVs shot down, the number of MX missiles saved in their silos, the number of MX missiles successfully launched (e.g., against a pindown threat), the fraction of defensive missiles successfully employed, etc. Some parameters of the engagement such as radar or missile reliability are introduced by Monte Carlo sampling of a probability distribution, so several runs may be needed to obtain an average outcome. No computer simulation can match the complexity of an actual engagement, and the results should not be interpreted as predictions of real system performance; however, simulations can be used to <u>compare</u> different system operating rules, hardware concepts, deployments, and other similar features.

If a BMD engagement simulation explicitly includes the C^3 subsystem, the importance of this subsystem can be evaluated by postulating different capabilities for the system and looking at the engagement outcomes. In particular, a system vulnerability may show up as a communication failure at some

response. These simulation results are strongly scenario dependent and should be employed with caution where attack scenarios are not well established. The kind of outputs produced by dynamic network analysis programs are:

- <u>Total Network Parameters</u>
  - Node and link probabilities of survival
  - Node and link availability as a function of time
  - Probability of correct message receipt as a function of time
- <u>Node-Specific Data Output</u>
  - Node dead times
  - Order of nodes receiving a message
  - Message arrival times at each intermediate and destination node

Optimal attacks against a network are difficult to compute for large networks because of the complexity of the problem. Optimal node or link attacks are often produced as a by-product of static network analysis, but the conditions for deriving these results are usually somewhat restrictive. Attacks to take advantage of nuclear effects on RF links have been studied for certain frequencies and propagation modes.* Many of the scenarios of interest to determining C^3 connectivity and correct message transmittance are directed at other targets (such as the MX field) with C^3 attacks incidental to the main objective.

4.2 EVALUATION OF C^3 CONTRIBUTION TO SYSTEM PERFORMANCE

The BMD C^3 System links together the sensors (SEC, Optical Adjunct aircraft, etc.), the interceptor missile farms, and the Battle Manager and ties these to Higher Authority and perhaps to MX. Some of the communications

*One useful report is: B. Gambill Jr., "Design for an Anticommunications Link Attack," GE75TMP-16. General Electric-TEMPO, Santa Barbara, Cal. October 1975 (U).

any two nodes; the minimum number of link cuts to disconnect a node, and several other indicators of inherent network survivability. There are dynamic network simulations that evaluate network performance as a function of time as the ability to communicate degrades during an attack. As a complement to these there are network attack optimization programs that help structure attacks against C^3 assets. As might be expected, there are no all-purpose programs or techniques that address all the BMD-related design and survivability questions.

A great many static C^3 network analysis programs have been written. There are even more programs designed to treat electrical networks, some of which are general enough to use on C^3 nets as well. C^3 network programs are frequently employed as design tools to insure adequate connectivity and data rate between various nodes at minimum cost. Some of these programs include reliability or node failure possibilities and determine the "robustness" of the system to arbitrary removal of various nodes and links. A typical program of this genre was developed by the Air Force Weapons Laboratory.* Codes of this type are especially useful in designing C^3 systems that will be subject to attack, especially when used in conjunction with attack optimization programs. GTE has used a network analysis program to analyze the connectivity of BMD-type nodes connected by fiber optics cables. Details of this program are not known (to TITAN Systems) at this time.

Analysis of network response to a nuclear attack is the basic purpose of several of the systems analysis codes listed in Section 4.1.4, including WEDCOM, NUCOM, SIMBAL, HFNET, PNAC, and STRAT COMMAND. These programs have the unique capability of determining link outage and recovery as a function of time from nuclear interference with RF propagation. Some of the programs can include a jamming threat as well as nuclear attack. This type of dynamic network analysis code is typically a Monte Carlo simulation and several iterations are needed to gather any statistical information about the system

*William P. Dotson, Jr., "Network Analysis and Reliability Assessment of Systems," AFWL-TR-74-138. The Air Force Weapons Laboratory, Kirtland AFB, N.M. June 1974 (U).

The findings of this short survey of propagation codes are summarized below:

- All of the codes for evaluating nuclear effects on C^3 systems are large and complex
  - Program utilization requires skilled personnel
  - Data preparation can be time-consuming
  - In many cases no simple analysis of nuclear/C^3 problems is feasible
- Most of these programs have been under development for several years
  - Several have up-to-date nuclear phenomenology models
- Unfortunately the C^3 codes identified here do not really address the BMD problems well
  - Most of the C^3 codes are structured for long (> 1,000 km) path length
  - Only NUCOM and NORSE cover frequencies of primary interest to BMD
  - Late-time phenomenology (> 30 minutes) is carefully treated by these codes, but is not of critical importance to BMD

The conclusion is that the existing codes are probably not adequate for the entire range of BMD C^3 V&H issues.

4.1.5 Network Analysis

The nodes and links that comprise a communications system collectively constitute the C^3 network. The overall survivability of the C^3 system and its ability to transmit the messages that allow BMD to operate is a function of the network properties as well as the vulnerability of individual nodes and links. Network performance and resistance to damage can be determined by several different types of computer programs. There are static network design programs that can compute the number of redundant paths between

- Systems Analysis Codes

  - SIMBAL
  - HFNET
  - RANC
  - PNAC
  - STRAT COMMAND

Research codes tend to be based on "first principles" with physics modeling as complete as is possible. The general purpose of these codes is to increase our understanding of both communications and nuclear effects phenomenology and of their interactions. Since these codes are research tools they are continually being changed and are, as a rule, poorly documented. MRCSIM is a collection of programs usually run in three parts for analysis of selected propagation problems. SCENARIO has some documentation; it uses a high altitude grid and a hydro-code-like approach to satellite communications. The NOSC (Naval Ordnance Systems Command) codes are detailed propagation simulations mostly at lower frequencies. These are combined with WEPH code phenomenology to give nuclear interference effects.

Engineering codes will use the most accurate representation of the phenomenology consistent with our understanding of the technology, unless computer requirements become prohibitive. These programs can be used for studies on problems of restricted scope, but are not usually fast enough for extensive parametric analysis. Most of these programs are documented and available within the community for C^3 and nuclear effects studies.

The final category of C^3 programs are those used for systems analysis. These programs contain approximations or phenomenology limitations so that either very large problems can be handled, or parametric analysis can be done for smaller problem sets. All of the codes listed above, in all three categories, are limited as to the frequencies they cover, the propagation modes treated, the time frame of interest, and the generality of the computer modeling.

4.1.4 RF Link Evaluation

RF links that may be a part of the BMD C^3 system include both transmissions to and from remote nodes (particularly Higher Authority and the Optical Adjunct aircraft) and radio links between the various BMD components. Frequencies mentioned for these RF connections include VLF, HF and UHF. Nuclear weapon bursts generate ionized regions that interfere with RF propagation in several different ways, depending on frequency, propagation mode, burst yield and altitude, and other factors. The interference phenomena, often loosely termed "blackout", are quite complex and this complexity is reflected in the computer codes that have been developed for C^3 link analysis. A summary description of several of these computer codes was compiled recently as part of a survey of literature of value to BMD C^3 V&H studies.* The major findings of that report are extracted below.

Computer programs for analysis of nuclear effects on electromagnetic propagation can be grouped into one of three categories: research tools, engineering codes, and systems analysis codes.

- Research-Oriented Codes
  - MRCSIM
  - SCENARIO
  - NOSC Propagation Codes
- Engineering Codes
  - WEDCOM
  - NUCOM
  - ROSCOE
  - NORSE
  - WEPH

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*R. Curtis Lee, "Applicability of Existing C^3 Vulnerability and Hardness Analyses to BMD System Issues." Report No. R-20-82-004. Titan Systems Inc., La Jolla, Calif. Jan. 13, 1983 (U).

Table 4-3. Typical Ground Facility Response Codes (Continued)

5. EMP (continued)

CEMPAT (HDL/KSC)	General purpose analytical and data managements.	Performs coupling and circuit analysis required for a complete system EMP assessment.
FOURA	Fourier transforms	Computes Fourier transforms of known one- or two-dimensional functions.
GRABLE	EMP-induced currents and voltages	Computes EMP-induced currents and voltages on multi-conductor, buried communication cables. The code prints out the induced current and voltage time-waveforms for each of the conductors of the cable. Both the high-altitude and the near-surface burst cases can be calculated.
CABLE	Cable current induction	Calculates current induced on simple cables having arbitrary terminations. Both E and H field coupling accounted for.

6. THERMAL RADIATION

NAME	PURPOSE	DESCRIPTION
MITAS (MARTIN)	General one-, two-, or three-dimensional transient or steady thermal analysis	Thermal analyzer program evolved from CINDA 36; uses network analogy.

Table 4-3. Typical Ground Facility Response Codes (Continued)

3. NUCLEAR RADIATION

NAME	PURPOSE	DESCRIPTION
ANISN (ORNL)	X-ray, neutron, prompt and secondary gamma	Computes the particle fluence as a function of range, energy, and angle for any one-dimensional configuration (plane slab, sphere, or cylinder) by solving Bolzman transport equation, uses the method of discrete ordinates with coupled, group averaged cross sections.
TDA (ORNL)	Time dependent version of ANISN	Time dependent one-dimensional discrete ordinates transport code using multigroup cross-sections.
SAM-CE (MAGI/KSC)	Neutron and gamma ray transport	A Monte Carlo code that computes the time-dependent transport of radiation through an arbitrary material composition. Uses point cross sections. Uses very efficient "bounded estimator" scoring procedures at point detectors.
MORSE-CG (ORNL & SAI)	Radiation transport of x-rays, gammas, and neutrons	A multigroup neutron and photon Monte Carlo time-dependent transport code with a 3-D general geometry package (combinatorial geometry). Can be run in both forward and adjoint modes.

4. TREE (Transient Radiation Effects on Electronics)

NAME	PURPOSE	DESCRIPTION
NET2(HDL)	TREE	Circuit analysis and design.
SCEPTRE (AFWL)	TREE	Circuit analysis and design; limited by models of active devices (observation is true for any TREE code).
CIRCUS (BOEING)	TREE	

5. EMP

NAME	PURPOSE	DESCRIPTION
SUPER. (AFWL)	Repository of device parameter capabilities for damage assessment.	Stores and manipulates failure data for diodes, transistors, linear integrated circuits, digital integrated circuits and passive devices.
NANAP2 (AFWL/FSC)	Hardness assessment and work analysis program for steady-state AC circuit analysis	Uses nodal analysis to compute the response of a linear electrical network. Computes the EMP input current and voltage required to burn out a semi-conductor junction isolated from the input by an electrical network.
NEC	Antenna and EMP electromagnetic response analysis	Used for analyzing electromagnetic response of an arbitrary structure consisting of wires and surfaces in free space or over a ground plane. Numerical solution of integral equation for induced currents.

Table 4-3. Typical Ground Facility Response Codes

1. AIRBLAST/GROUND SHOCK

NAME	PURPOSE	DESCRIPTION
ADINA (MIT/KSC)	Three-dimensional non-linear finite element structural response code.	Structural response of complex models may be performed subject to thermal or dynamic pressure loads. Finite element library includes thick shells, 3-D blocks, beams, trusses, etc. Materials models include elastic-plastic soil, concrete crushing model, fracture, etc. 3-D color graphics via a modified MOVIE-BYU program are available.
BOSOR 5	Buckling of elastic-plastic shells of revolution including large deflection and creep.	Treats segmented and branched shells with discrete ring stiffeners, meridianal discontinuities and multi-material construction. Prebuckling analysis presumes axisymmetric behavior. Bifurcation buckling loads correspond to either axisymmetric or non-axisymmetric buckling modes.
[illegible]	Large deflection, anelastic dynamic response of multi-layered shells to transient surface and in-plane loads.	Treats infinite length shells in plane strain or axisymmetric finite shells. Shells may have variable thickness and consist of an arbitrary number of layers. Arbitrary initial conditions and transient loads are treated by user-coded subroutines. Solves finite difference approximations to general tensor formulation of Kirchoff shells.
HONDO I & II (SANDIA)	Large deformation dynamic response of 2-D solids.	Large deflection codes that treat elastic, elastic-visco-plastic, crushable foam, and soil behavior. Sliding interfaces allowed. Uses four-node isoparametric quadrilateral finite elements and a central difference time integrator.

2. GROUND MOTION/STRUCTURE RESPONSE

NAME	PURPOSE	DESCRIPTION
HELP		HELP is a general multi-material Eulerian finite difference program for the solution of problems in compressible fluid flow with strength effects included. This code is especially suited for flows involving extreme distortions such as the region in the near vicinity of underground explosions or the energy coupling of air blast into the ground.
SAGE		SAGE is a two-dimensional linear elastic finite difference computer code for modeling stress waves propagating in a geologic environment. Modifications for various kinds of anisotropic and anelastic material behaviors may be performed as long as the displacements remain small.
SWIS-SMI		SWIS-SMI is a one, two, or three-dimensional nonlinear finite element code for modeling the response of a structure and the surrounding soil continuum to high stress loading. The code treats the constitutive models in the explicit fashion typical of finite difference codes rather than by the usual process of matrix inversion. A more efficient procedure for handling nonlinear material properties is thereby attained.

damage response calculations, gives a hypothetical example of each, and indicates in very general terms the kinds of data about the design needed to make a vulnerability assessment.

The variety of possible calculations dealing with C^3 node response is only hinted at in Table 4-2. It is apparent that these kinds of analyses are an intimate part of the design process and that verification of system hardness at this stage must be very selective. Mechanical design, even to the severe environment levels of interest to BMD, is part of standard engineering practice and should not require as much Program Office attention as the unique nuclear environments. These environments include EMP, nuclear radiation, and thermal radiation. There are computer programs available for many, but not all, aspects of the node damage response problem. A typical set of these codes, along with brief descriptions, is provided in Table 4-3. Because of the complexity of these programs and their extensive data requirements, analyses of system response should only be undertaken by groups who are intimate with the technologies involved. Only those who are experienced in these areas can properly formulate the problem to be solved, identify the computerized tools to be used, quickly assemble the data needed, and interpret the output correctly.

4.1.3 Fiber Optic Link Evaluation

One of the possible communications links within the BMD complex is buried fiber optics (F/O) cable. Fiber optics have the advantages of high data rate and insensitivity to EMP, but their performance is degraded by exposure to nuclear radiation. At high overpressures the F/O cables are subject to ground shock and ground motion which can shear the cable. Vulnerability to both of these environments can be reduced by burying the cable deeper, but deep burial increases the cost of laying the cable. Calculational procedures are therefore needed to evaluate cable hardness to radiation and ground motion as a function of burial depth and geological parameters. Ground motion analyses for F/O cables have been carried out by GTE-Sylvania and others as part of the MX C^3 studies and some work applicable to BMD has been done.

- a fundamental decision regardinng whether deep burial is even to be considered as an option

- given that deep burial is an option, a choice between installation via trenching or via deep burial, a decision which is keyed to both cost and balanced survivability.

For the V&H efforts dealing with the RF network, the major milestones are:

- high level decisions regarding how and when BMD communicates with both HA and MX

- selection of RF frequency band(s), a decision which is keyed on striking a balance between competing trends.

Another major milestone is one which also hinges on the decisions regarding HA and MX, and that is the decision to shield, harden, or use "as is" the existing line of COMSEC equipment. The importance of this decision is to make it as soon as possible in order to provide the necessary lead time to develop new COMSEC, if necessary.

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